GB-1981-10

(12) UK Patent Application (19) GB (11) 2 073 616 A

(21) Application No 8111415
(22) Date of filing 10 Apr 1981
(30) Priority data
(31) 3014142
(32) 12 Apr 1980
(33) Fed Rep of Germany (DE)
(43) Application published 21 Oct 1981
(51) INT CL³ B05B 17/06
(52) Domestic classification B2F 150 324 FC
(56) Documents cited None
(58) Field of search B2F F4T

(71) Applicants
Battelle-Institut e.V.,
Am Römerhof 35, 6000
Frankfurt/Main 90,
Federal Republic of
Germany
Leybold-Heraeus GmbH,
Wilhelm-Rohn-Strasse
25, 6450 Hanau, Federal
Republic of Germany

(72) Inventors
Ernst-Guenter Lierke
Wolfgang Heide
Rudolf Grossbach
Karl Floegel
Hartmut Erdmann

(74) Agents
D. Young & Co.,
10 Staple Inn,
London WC1V 7RD

(54) Apparatus for atomising liquids

(57) Apparatus for atomising liquids comprises an ultrasonic excitation system (1, 2, 5) for a bending resonator (4) and means to deliver liquid (6) to be atomised to a velocity nodal region of the resonator (4). The resonator (4) may be conical or otherwise shaped so as to have at least one surface inclined to a longitudinal axis of the excitation system (1, 2, 5). The length of the ultrasonic excitation system may be at least approximately equal to $(2n+1)\lambda/4$, where n = 0, 1, 2, 3, ...

Fig.1.

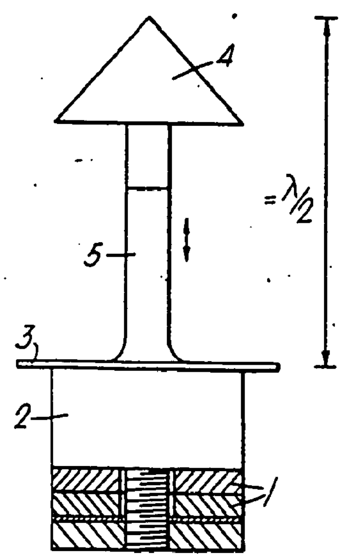
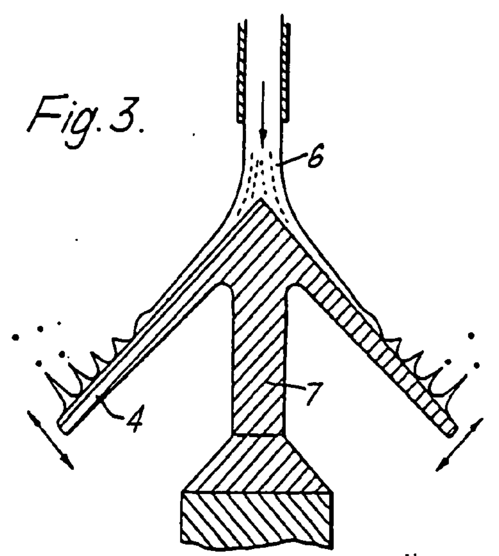


Fig.3.



239-102.2

GB 2 073 616 A

Fig.1.

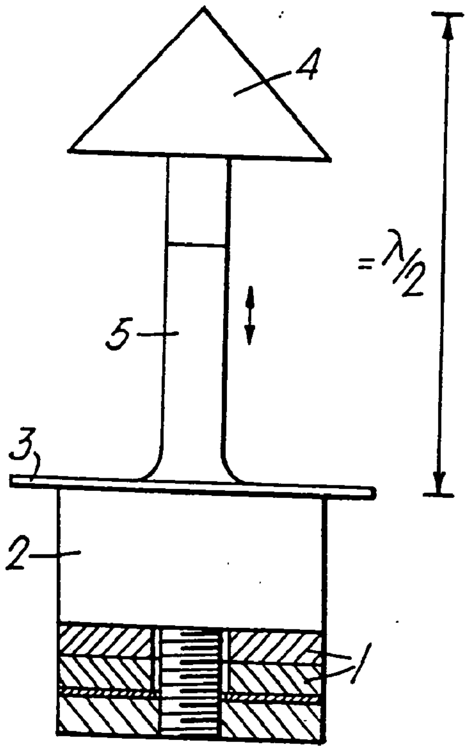


Fig.2.

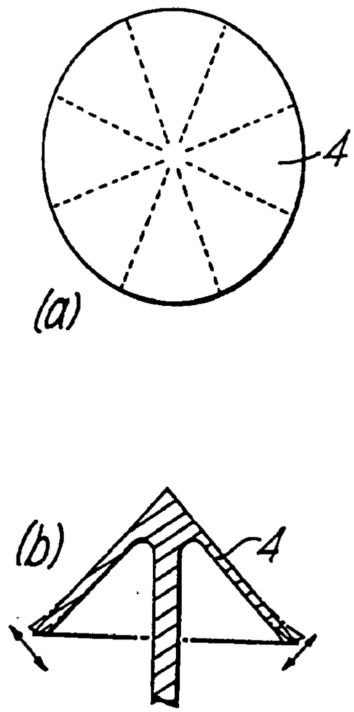


Fig.3.

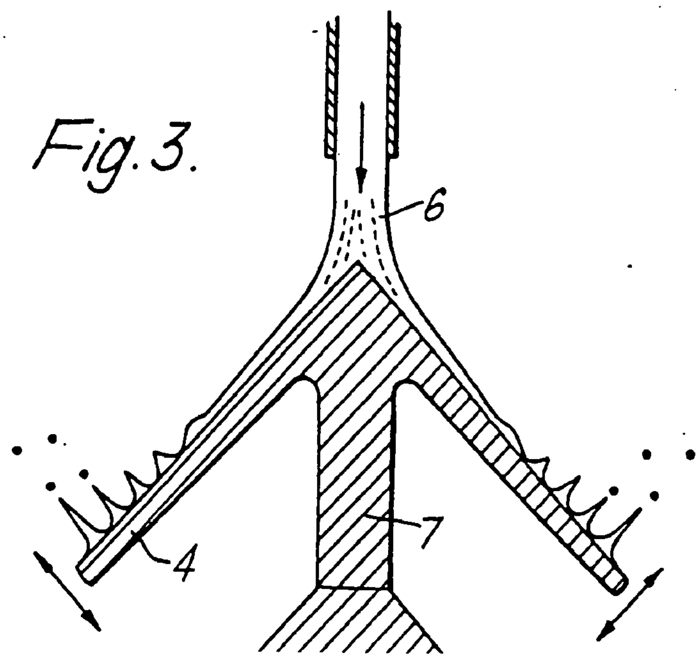


Fig. 4.

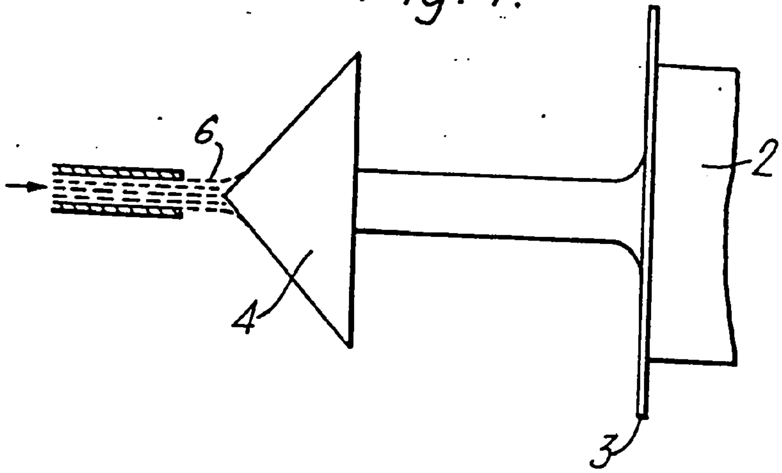


Fig. 5.

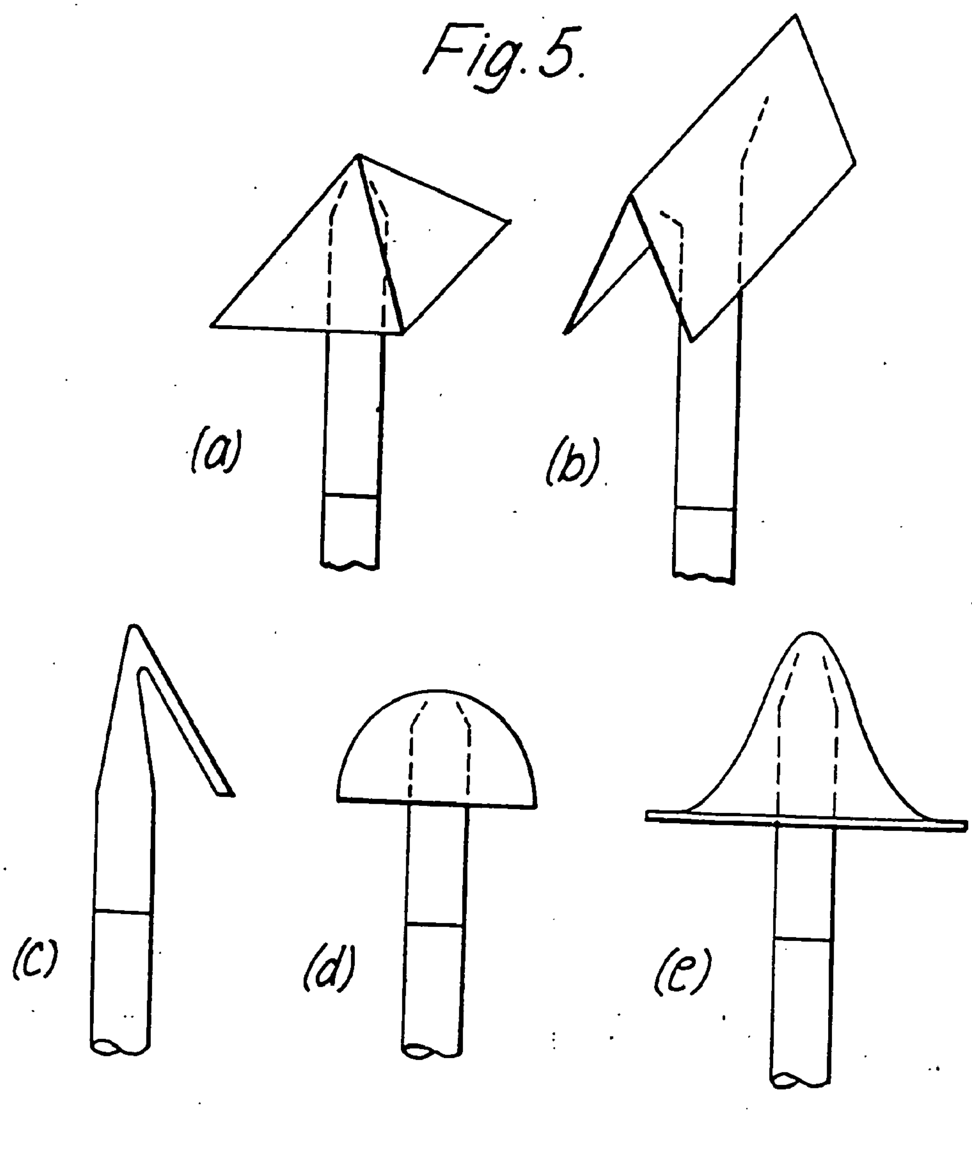


Fig. 7.

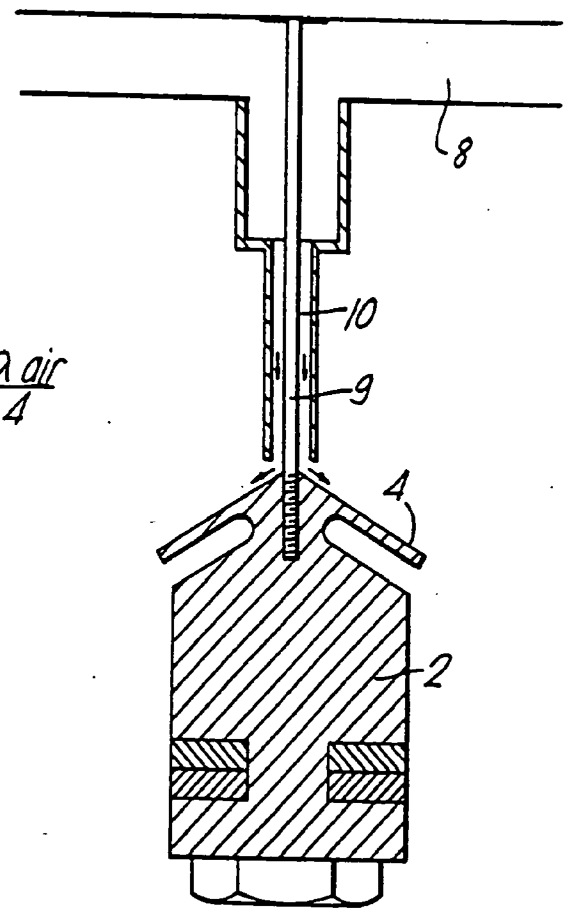


Fig. 6.

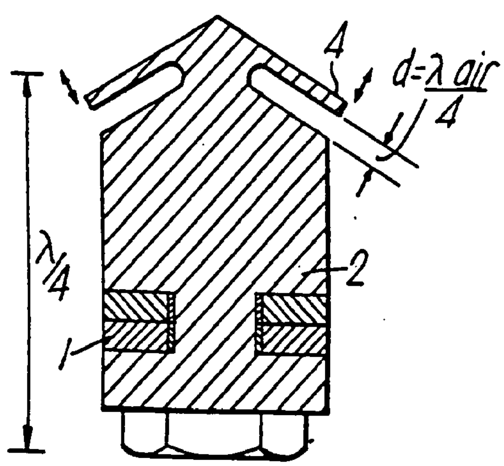


Fig. 9.

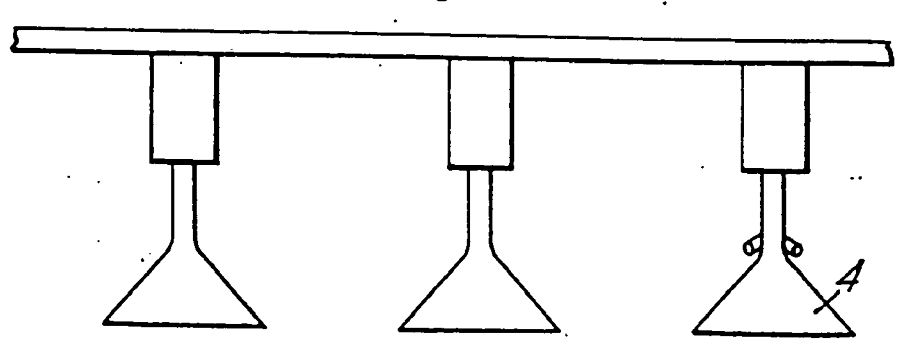
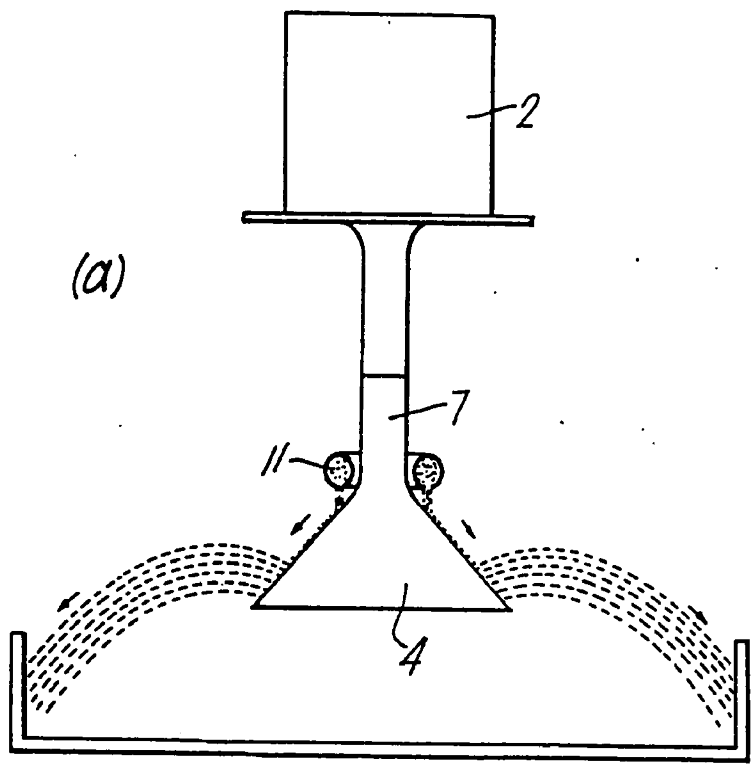


Fig. 8.

(a)



(b)

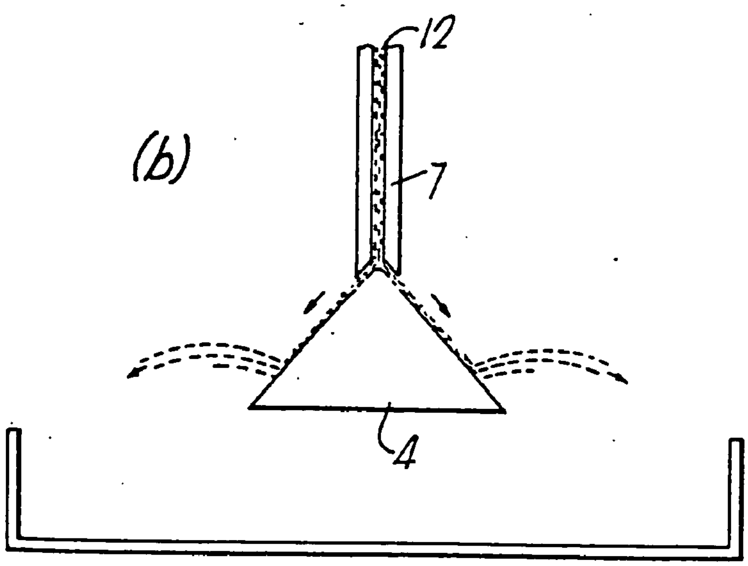


Fig. 10.

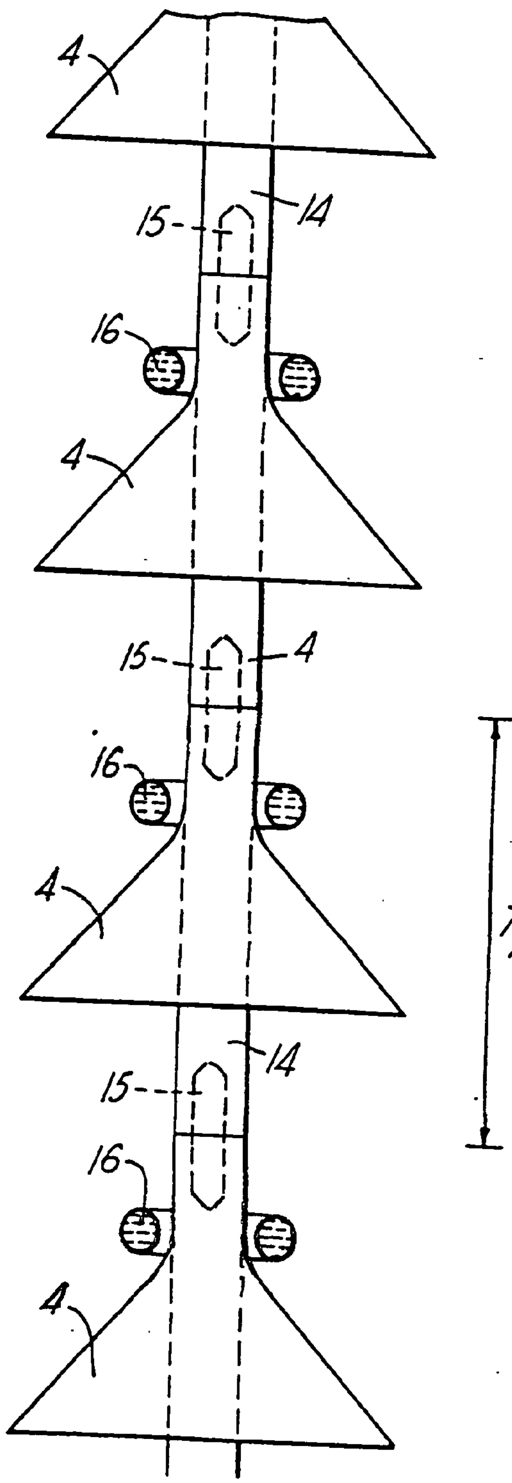
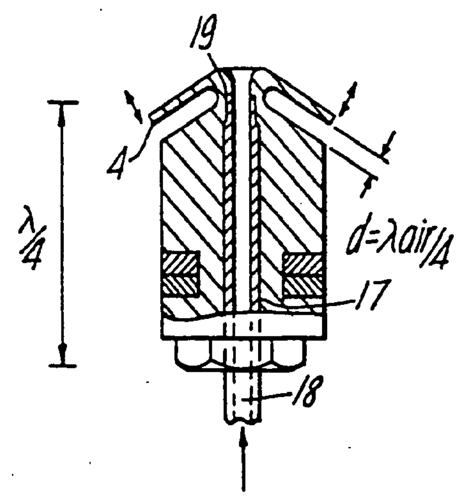


Fig. 11.



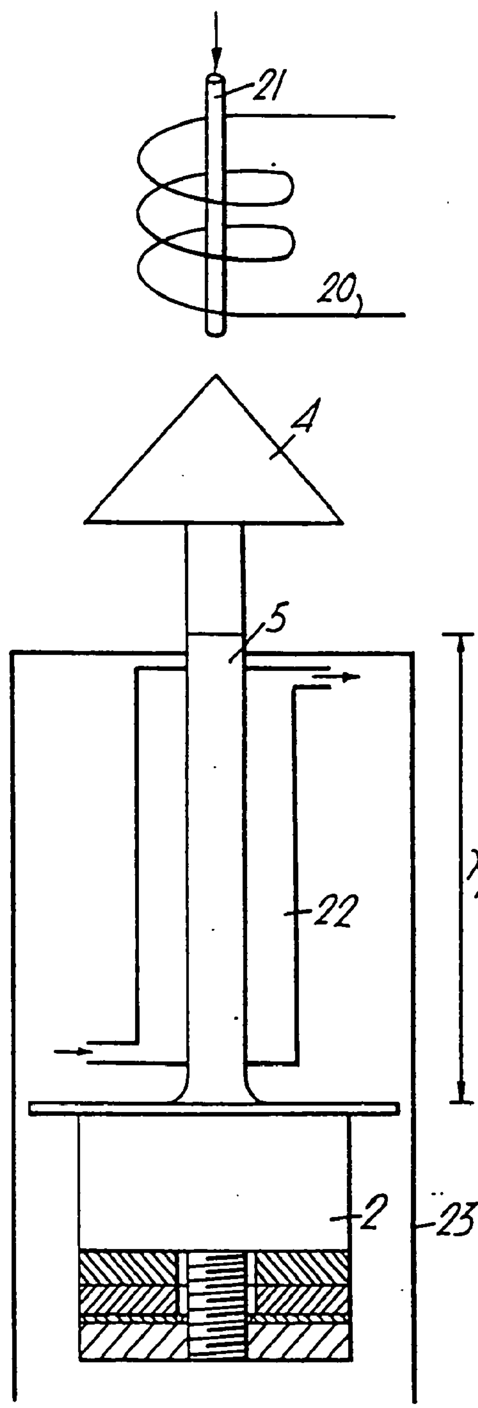
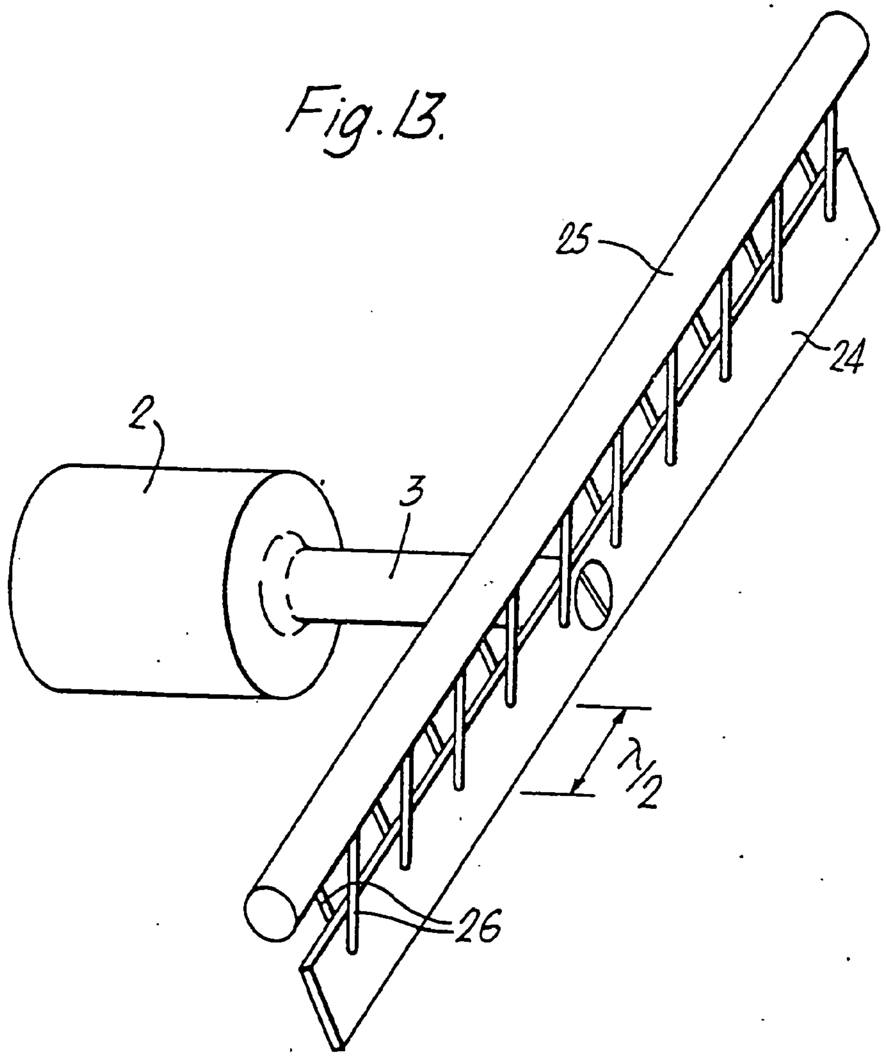


Fig. 12.

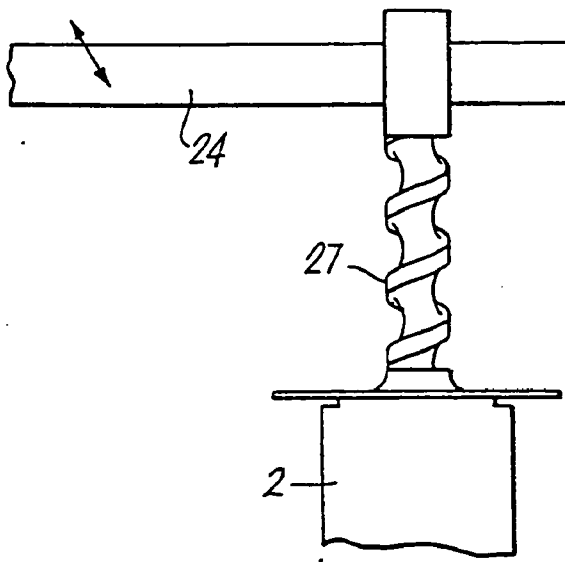
Fig. 13.



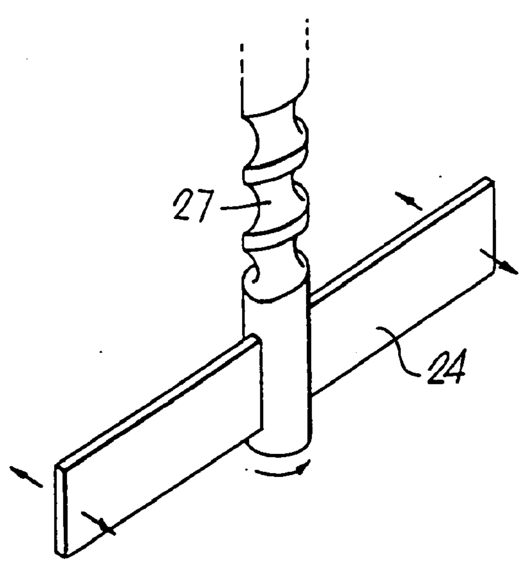
2073616

8/10

Fig. 14.



(a)



(b)

Fig. 15.

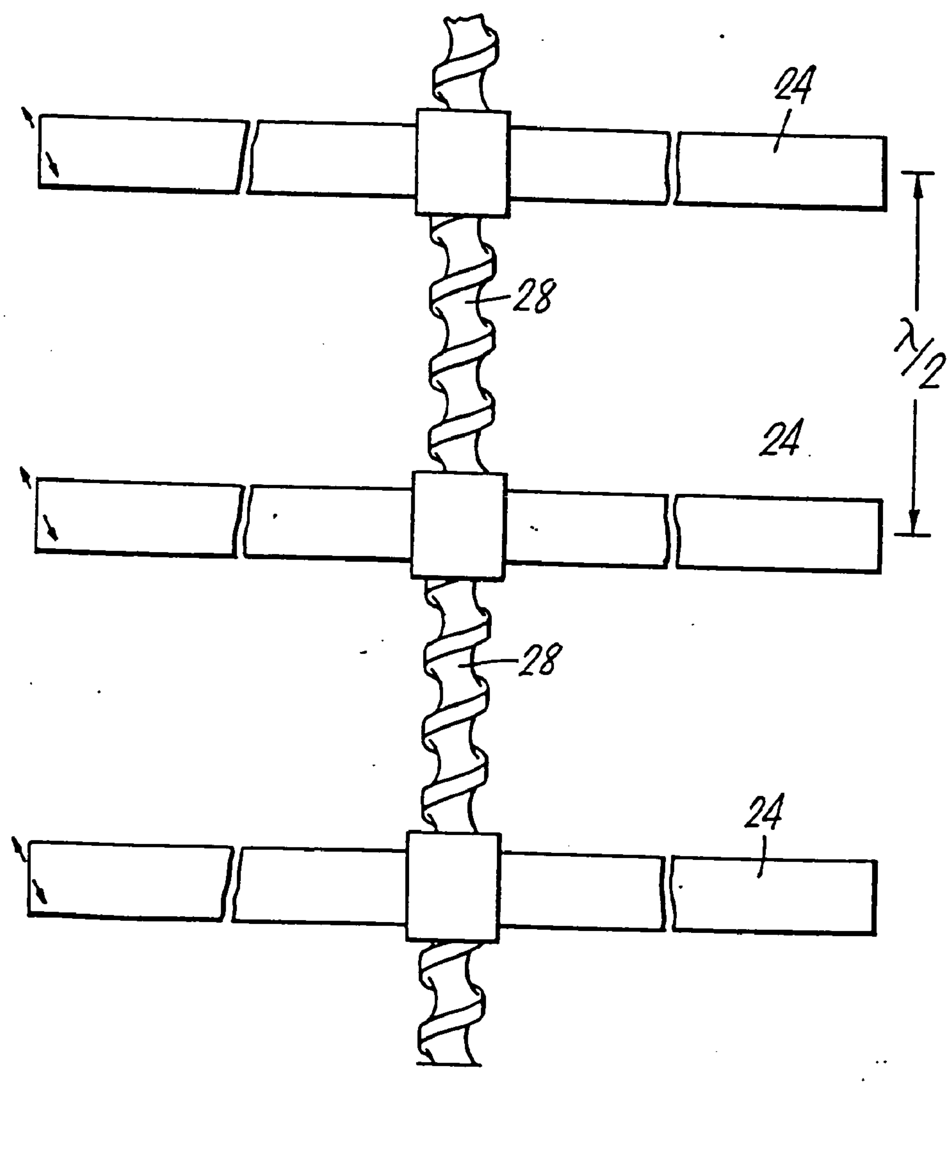


Fig.16

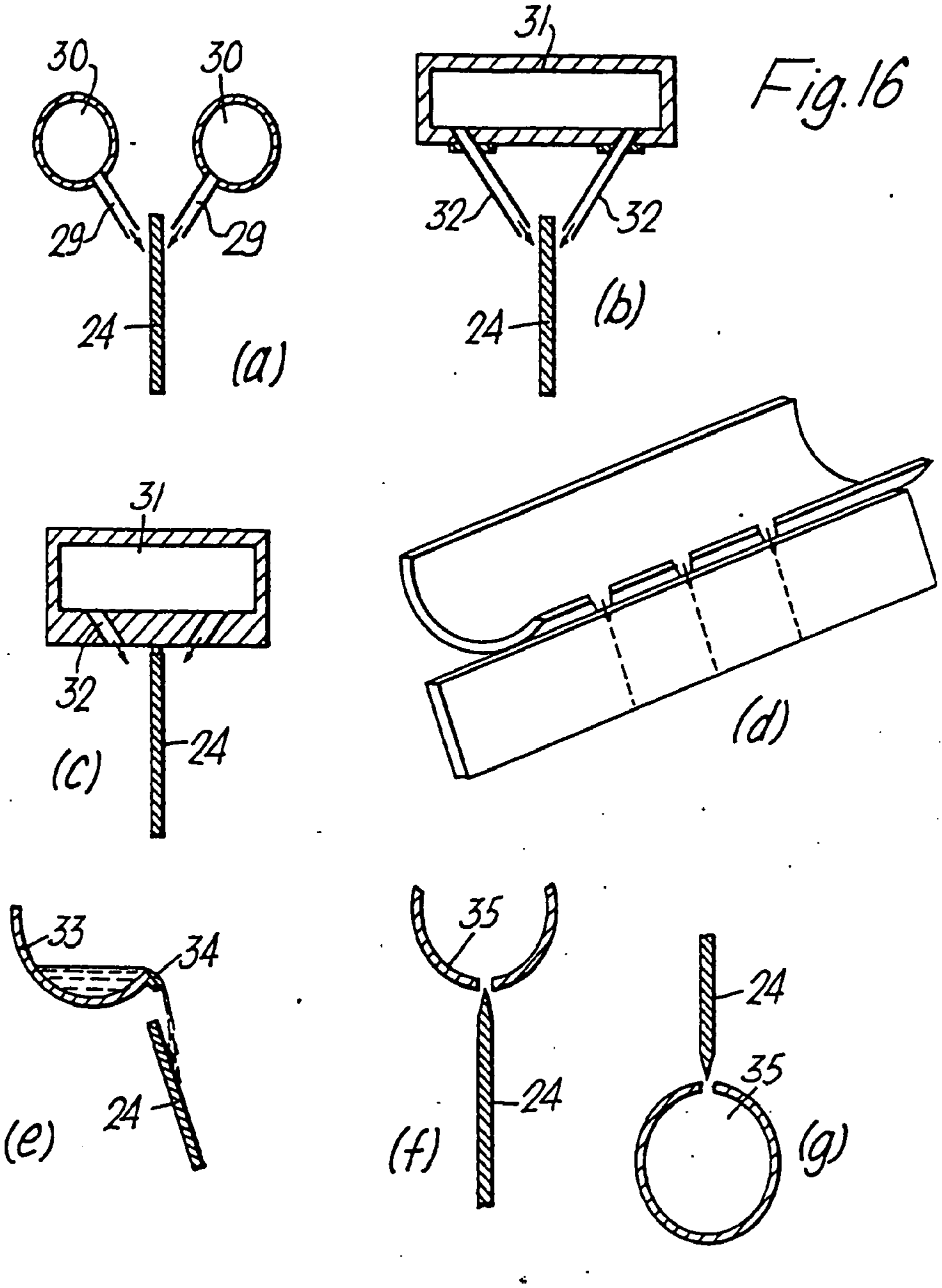
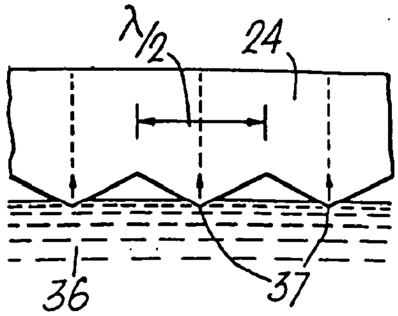

30
30
29
29
24
(a)
31
32
32
24
(b)
31
32
24
(c)
(d)
33
34
24
(e)
35
24
(f)
24
35
(g)

Fig.17.


λ/2
24
36
37

SPECIFICATION

Apparatus for atomising liquids

This invention relates to apparatus for atomising liquids.

In conventional ultrasonic capillary wave automisers, a fine dispersion effect is produced by cutting off drops from a stationary capillary wave grid of velocity nodal lines arranged in a chessboard-like manner, the grid being formed on a thin film of liquid which is excited by a surface of an oscillating solid body. The atomisation effect requires an excitation amplitude, which is dependent on the frequency and various parameters of the liquid, in respect of the oscillating solid body surface, and a suitable thickness of the film of liquid. If the film is excessively thin, drops cannot be formed, while if the film is excessively thick, damping prevents effective capillary waves from being stimulated in the liquid.

In order to achieve an optimum specific atomisation throughput in relation to surface area, of a few litres per hour and cm^2, with low-viscosity liquids, the liquid must be continuously fed on to the atomiser surface in such a way as to maintain the optimum possible thickness of film over the maximum area of the oscillating surface.

With the convention mode of supplying the liquid, through an axial bore in the ultrasonic atomiser, the required manner of operation can be achieved only up to relatively low levels of throughput of less than 5 litres/hour. However, when an internal liquid supply arrangement of this kind is used, cavitation sputtering occurs, particularly at higher rates of through-put, and cavitation sputtering results in unacceptable impairment of the drop spectrum. This effect can be prevented by using an external liquid supply arrangement, comprising a plurality of pipes. Such a construction may be uneconomical and not the optimum arrangement under some circumstances, at high rates of throughput. Added to this is the fact that the known apparatuses do not make it possible to effect separation in dependence on particle size, for example when producing powder.

According to the invention there is provided apparatus for atomising liquids, the apparatus comprising an ultrasonic excitation system having a horizontal axis, a bending resonator coupled to the ultrasonic excitation system to be oscillated at an ultrasonic frequency having a wavelength λ, and means for delivering a liquid to a velocity nodal region of the bending resonator, wherein the bending resonator has at least one surface which is inclined with respect to the longitudinal axis of the excitation system and the length of the ultrasonic excitation system is at least approximately equal to $(2n+1)\lambda/4$, where n is 0 or an integer.

The invention also provides apparatus for atomising liquids, the apparatus comprising an ultrasonic excitation system having a longitudinal axis, a bending resonator coupled to the ultrasonic excitation system to be oscillated at ultrasonic frequency, and means for delivering a liquid to velocity nodal regions of the bending resonator, the bending resonator being in the form of an elongate narrow strip having a plurality of parallel velocity nodal lines.

The overall length of the excitation system in the latter case can be equal to n, $\lambda/2$, where n is an integer, and there may be a velocity antinode at its intersection with the bonding resonator.

Embodiments of the present invention described below seek to make it possible to achieve atomisation of a high liquid throughput at an outimum level of efficiency, and to ensure that the delivery of liquid is subjected to minimum cavitation and the power consumption is minimised.

Apparatus embodying the invention may comprise a conventional ultrasonic amplitude transformer and a bending resonator which is mechanically connected thereto and which has the same resonance frequency. The connection between such two parts may be such that the bending resonator can be replaced as a separate unit. In simple cases, the resonator is a radially symmetrical hollow cone or an elongate metal strip.

The bending oscillation of the resonator is produced in the embodiment of the invention described below by an axial excitation system. The excitation system is preferably a piezoelectrically excited compound oscillator which can be in the form of a step or tapped transformer or with a conical, exponential or similar contour.

However, the axial excitation effect may also be partially converted into a torsional component, whereby, with a suitable design, bending oscillation of the linear resonator is also produced.

Apparatus embodying the invention may be used in particular in air humidifiers in air conditioning equipment, oil burners, as metal atomisers for producing powder from atomised melts, and as atomisers for atomising solutions, suspensions and emulsions for producing powder by evaporation of the liquid components. It may also be used in process chambers at reduced or increased gas pressure, at lower or higher temperatures, and in inert or reactive gas atmospheres, so that it is possible to conceive of a large number of technical uses in processes on an industrial scale, because of the high output which can be achieved with minimum power consumption. In the latter use, gasification or degasification of liquids in particular can be achieved by a diffusion effect. In this respect, adjustment of the angle of the atomisation surface makes it possible for the particles of liquid to cover a long flight path so that the entire volume of the process chamber can be put to optimum use.

Advantages which may be achieved by embodiments of the present invention are essentially that large amounts of liquid can be conveyed to the atomiser surface by way of a central supply means, under optimum conditions. In addition, cavitation is eliminated or at least reduced at the liquid supply location(s), in spite of the film of liquid initially being of great local thickness. Due to the parabolic charac-

The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

teristic of the cloud of liquid droplets generated, the distances between the droplets continuously increases so that the usual tendency of a dense cloud to coagulate is greatly reduced. Due to the increase in the diameter of the trajectory of the droplets with the square of the diameter of the droplets, it is possible to effect particle separation in the production of powders. The inclined position of the atomiser surface provides that over-critical damping of the atomiser oscillation is prevented. The excess liquid flows away over the edge of the atomiser, without detrimentally affecting the function thereof.

Surfaces of any desired width may be uniformly sprinkled with the atomised liquid by the strip-like bending resonator being of suitable length. It is possible to double the output, by providing for a supply of liquid on both sides.

By using a conical bending wave atomiser with a diameter of 50 mm, for example with a working frequency of 20 kHz and with an HF-power consumption of less than 10 watts, about 150 litres/hour of water can be atomised in drops of about 40 microns. A larger cone surface area makes it possible considerably to increase the output, which can be reduced to zero by reducing the supply of liquid, without changing the diameter of the drops. In addition, apparatus embodying the invention can be used without difficulty at frequencies of up to about 100 kHz. Accordingly, this results in the mean drop diameters being smaller, with almost the same specific outputs in relation to surface area, of some litres/hour and per cm^2.

The invention will now be further described, by way of illustrative and non-limiting example, with reference to the accompanying diagrammatically simplified drawings, in which:

Figure 1 is a general view of an ultrasonic atomiser embodying the invention, having a hollow cone acting as a bending resonator;

Figures 2*a* and 2*b* are a plan view and a view in longitudinal section, respectively, of the conical bending resonator of the atomiser of Figure 1;

Figure 3 is a view in longitudinal section through the conical resonator, with a vertical supply of liquid;

Figure 4 shows an embodiment wherein the liquid is supplied horizontally;

Figures 5*a* to 5*e* show alternative embodiments of the bending resonator;

Figure 6 shows a further embodiment wherein the conical resonator is connected to an excitation system therefor in such a way that the overall length of the system is $\lambda/4$;

Figure 7 shows one possible technique of mounting the apparatus shown in Figure 6;

Figures 8*a* and 8*b* show alternative forms of the means for supplying the liquid, in an apparatus in which the cone is in a reversed position compared to its position in the previously shown embodiments;

Figure 9 shows a linear arrangement of a plurality of atomisers wherein the bending resonators are in the form of hollow cones in reversed positions;

Figure 10 shows a plurality of conical bending resonators which are connected together in a cascade formation with a common excitation system;

Figure 11 shows an atomiser with a conical bending resonator and with liquid supply through the centre from the reverse side;

Figure 12 shows an embodiment with heating and cooling means, which is suitable for the atomisation of metal melts;

Figure 13 shows an atomiser embodying the invention wherein the bending resonator is in the form of a narrow metal strip;

Figures 14*a* and 14*b* show two further embodiments wherein the bending oscillations of the resonator are produced by torsional excitation;

Figure 15 shows a plurality of atomisers as shown in Figure 14*a* and Figure 14*b*, connected together in a cascade formation;

Figures 16*a* to 16*h* show some possible forms of the liquid supply or delivery means; and

Figure 17 shows a further possible form of the liquid delivery means.

Figure 1 shows an ultrasonic atomiser embodying the invention, the atomiser comprising an ultrasonic excitation system in the form of a coupling oscillator 2 which is excited by means of two piezoelectric ceramic discs 1 and which is in the form of an amplitude transformer which is stepped at a velocity node 3. Such oscillators are described for example in DOS (German laid-open patent application) No. 29 06 823. This embodiment comprises a bending resonator 4 which is in the form of a rotationally symmetrical hollow cone and which is disposed at an end, remote from the step 3, of a slender cylindrical narrower portion 5 of the ultrasonic excitation system (1, 2, 5). The overall length of the ultrasonic excitation system is $(2n+1)\lambda/4$, wherein n is 0 or an integer. In the embodiment shown in Figure 1, the said length is $3\lambda/4$, and the distance between the step 3 and the tip of the resonator 4, that is to say the length of the cylindrical narrower portion 5, is $\lambda/2$, so that a velocity nodal point is disposed in the region of the tip of the cone. The dimensions of the resonator 4, that is to say the thickness, diameter and taper angle of the cone, are so selected that, at the desired working frequency, bending resonances are produced, with a greater or smaller number of nodal radii and/or nodal circles. Preferably, the resonance used is a natural resonance at which the resonator 4 oscillates with nodal radii and at an amplitude which increases from the centre, that is to say the tip of the cone, to the periphery, so that liquid directed on to the tip of the cone can be spread out towards the peripheral region, with the thickness of the film of liquid decreasing.

Figure 2*a* shows the nodal radii (dotted lines) in plan view, while Figure 2*b* shows the bending oscillation of the hollow cone resonator 4.

Figure 3 shows that liquid 6 to be atomised can be supplied axially on to the tip of the resonator 4 from above, in the form of a relatively thick jet or stream. As there is a velocity node in the region of the tip of the hollow cone 4, there is no stimulation of capillary waves at that point. There also cannot be any oscillation cavitation, as would be the case with a thicker film of liquid, at the amplitudes required for producing the atomisation effect. Accordingly, the liquid runs down over the surface of the cone without interference, while the thickness of the film steadily

decreases with increasing distance from the centre, with the amplitude of the movement of the atomiser increasing at the same time. This automatically results in the film being of the optimum thickness for the atomisation action. Atomisation is then effected in conventional manner by droplets being cut off from the capillary wave grid. The angle of inclination of the surface of the cone causes the droplets to be thrown axially symmetrically away from the atomiser, following approximately parabolic trajectories whose distance from the centre is approximately proportional to the amplitude v of the transducer, the density ρ of the atomised liquid and the square of the droplet diameter d. The mean droplet diameter d_m follows in known manner from the following capillary wave formula:

$$d_m \approx \frac{\lambda k}{4} = \frac{1}{2}\sqrt[3]{\frac{\delta.\pi}{\rho.f^2}}$$

where

δ = surface tension

λk = capillary wave length; and

f = frequency.

The droplet spectrum is described by a relatively narrow logarithmic normal distribution.

Figure 3 also shows the resonator 4 secured to the excitation system by way of a coupling portion 7.

In an alternative form of the arrangement shown in Figure 3, the liquid may be delivered in a horizontal direction, as shown in Figure 4.

If the ressonator 4 oscillates with a plurality of nodal circles, it could also be necessary or desirable for the means for delivering the liquid to be directed not just centrally on to the tip of the cone but also in the region of the nodal circles.

Figures 5*a* to 5*e* show a selection of possible forms of the bending resonator, Figure 5*a* (for example) showing a resonator in the form of a hollow pyramid. In all these cases the resonator has at least one inclined or curved atomisation surface and the liquid is supplied to the region of a velocity nodal point or nodal line. In the embodiment shown in Figure 5*b*, the liquid may be delivered along the common edge at which the two surfaces intersect each other, for example through an opening of slot-like configuration.

Figure 6 shows an embodiment comprising a compact version of the atomiser shown in Figure 1, again with a conical bending resonator 4. In this case, the overall length of the ultrasonic excitation system is, as shown, equal to $\lambda/4$ (n=0), so that there is a velocity node at the tip of the resonator 4. This embodiment is preferred because it can be produced relatively simply by providing an aperture in the cylindrical excitation system, the aperture defining the resonator 4. In order to prevent the reflection of air-borne sound to the rear of the resonator 4, which would consume unnecessary power, the width d of the aperture, that is to say the distance between the peripheral end of the cone 4 and the excitation portion 2, should be at least approximately equal to $(2n+1)\,\lambda_{air}/4$, where n is equal to zero (as in the illustrated case) or is an integer.

The embodiment shown in Figure 6 may be secured in a simple manner to a mounting means 8. For this purpose, as shown in Figure 7, the tip of the cone 4 is provided with a bore into which a mounting member 9, for example a pin, tube, wire or the like, is passed. In this case, a liquid delivery means or passage 10 may be disposed coaxially around the mounting member 9. Other alternative forms of atomiser embodying the invention may be fixed in a similar manner. The fixed support means 8 may be a liquid supply conduit from which the liquid is passed through the passage 10 to the region of the tip of the cone.

In the apparatuses shown in Figure 8*a* and Figure 8*b*, a conical resonator 4 is secured by means of its tip and by means of a coupling portion 7, respectively, to the excitation system 2, so that this mode of coupling represents a reversal of the embodiments described above. In Figure 8*a*, the liquid is supplied by way of an annular nozzle arrangement 11 which is mounted around the coupling portion 7 of the resonator, that is to say in the transitional region between the resonator 4 and the excitation system 2, 7. However, the liquid may be delivered into the region of the nodal point in any other manner, for example through an axial bore 12 in the excitation system with lateral outlet openings at the surface of the cone, that is to say in the region of the transition to the resonator 4, as shown in Figure 8*b*.

Figure 9 shows that a plurality of atomisers as shown in Figures 8*a* and 8*b* may be secured to a common liquid supply conduit. Other kinds of arrangements, for example circular arrangements, are also possible. Such an embodiment is particularly suitable for high rates of liquid throughput.

However, the bending resonators may also be connected together in a cascade formation and jointly excited. Such an embodiment is shown in diagrammatic form in Figure 10. The elements of the cascade comprise conical bending resonators 4 with coupling portions 14, which are identical from the point of view of material and dimensions. The overall length of an element of the cascade formation is, as shown, $\lambda/2$, and the elements of the cascade formation are each connected together at velocity antinodes, for example by screws 15. The individual elements of the cascade formation may instead be secured together by soldering or by any other suitable means. In another alternative form, the cascade formation is produced in one piece. The excitation system (not shown herein), which is common to the elements of the cascade formation, may be disposed both above and below the cascade formation. The supply of liquid may be effected in the manner already described hereinbefore. In this case, the coupling portions 14 are each provided in the region of the transition to the tip of the respective cone with an annular pipe 16 which includes liquid discharge openings.

A variant, shown in Figure 11, of the $\lambda/4$-construction with conical bending resonator which was described in greater detail with reference to Figure 6, is particularly suitable for use in oil burners, because of the manner in which the liquid is supplied. The excitation system 2 has an axial bore 17 which extends to the tip of the resonator 4. A tube 18, which is tuned to resonance, is passed through

the bore 17 and is fixedly anchored to the system, for example by screw means 16, in the velocity nodal region. The opening at the tip of the resonator 4 is somewhat rounded in order to provide for optimum distribution on the surface of the cone of the liquid which is passed through the tube 18 and which issues at the tip of the cone.

Figure 12 shows an embodiment wherein the resonator 4 is heated and temperature-sensitive parts of the excitation system 2 are cooled.

Heating of the resonator is effected for example by means of an induction coil 20 through which a metal melt 21 to be atomised is passed. Cooling is effected between two adjacent velocity nodal regions of the slender portion 5. For that purpose, the cooled region may be provided, for example coaxially, with a liquid or gas cooling means 22. The cooling means 22 is preferably disposed at the lower region of the slender portion 5. The cooling means 22 and the excitation system 2 may also be provided with a casing 23 to prevent any possibility of overheating having a detrimental effect.

Figure 13 shows an atomiser embodying the invention wherein the bending resonator is in the form of an elongate thin metal strip 24. The strip 24 is connected to the excitation system 2, 3 at an antinode. Atomisation surfaces of the strip 24 are disposed perpendicularly to the axis of the excitation system 2 and 3. By varying the axial direction of the excitation system, which extends horizontally in the form illustrated, it is possible to set a normal to the surface of the strip 24, and thus the direction of atomisation, at any desired angle of inclination. When axially excited, such a strip produces bending oscillations, wherein the nodal lines extend parallel to each other on the atomisation surface, and perpendicular to the excitation axis. The liquid may be supplied by way of a supply conduit 25 which is provided with liquid supply pipes 26 on both sides, in the region of the nodal lines. The liquid may instead be supplied on one side only, or only some nodal lines may be supplied with liquid. The liquid which flows along the nodal lines spreads out laterally of the nodal line towards the antinode, with the film of liquid decreasing in thickness, and the liquid is thus atomised.

Instead of being produced by axial excitation, the bending oscillation of the resonator may be produced by means of torsional excitation. Such a construction is shown in Figures 14*a* and 14*b*. A strip-like resonator 24, which is of an elongate, narrow form, is connected to the excitation system 2 by way of a spiral member 27. In this arrangement, a normal to the surface of the strip 24 is perpendicular to the axis of the excitation system 2. In general, for torsional excitation, it is sufficient for the narrow cylindrical portion of the excitation system to be only partly provided with a spiral member. The direction of atomisation is horizontal with respect to the axis of the excitation system so that the excitation system is not detrimentally affected when atomisation occurs. In this embodiment, the liquid may be supplied in a similar manner to the supply of liquid for the linear atomiser shown in Figure 13; other possible forms of liquid supply arrangements are described hereinafter with reference to Figures 16 and 17.

Figure 15 shows a cascade-like arrangement of linear bending resonators 24. The individual elements of the cascade formation, of length $\lambda/2$ (in the axial direction), which comprise a bending resonator 24 and spiral coupling portions 28, are secured together at the torsional velocity antiondes. The axial excitation system (not shown herein), which is common to all the elements of the cascade formation, may be disposed above or below the cascade formation. In general, it is not necessary for each section of the cascade formation to include a spiral member. It is also possible to use a cascade arrangement with the construction shown in Figure 13, although in that case there is no torsional excitation so that spiral members are not necessary. In a further embodiment, the bending strips which are arranged in the cascade formation may be disposed at different angular positions relative to each other.

Referring now to Figure 16*a*, it will be seen that the strip 24 may be supplied with liquid on both sides along the nodal line, by way of branch pipes 29, from supply conduits 30. Liquid may also be supplied in this way from a liquid reservoir 31 with suitable openings 32, as shown in diagrammatic form in Figures 16*b* and 16*c*.

In cases where there is a danger of blockage of the pipes carrying the liquid, it may be appropriate to use a semi-cylindrical container 33 with suitable openings or accessory members 34 for supplying the liquid, the openings or elements 34 being arranged in the region of the velocity nodes at a spacing of $\lambda/2$. These embodiments are shown in Figures 16*d* and 16*e*.

In the embodiment shown in Figure 16*f*, the strip-like resonator 24 is taken directly to an opening in a supply conduit or reservoir 35. In this arrangement, the liquid is distributed to the atomisation surfaces, starting from the velocity nodes. In the embodiment shown in Figure 16*g*, the liquid is sucked up along the nodal lines from a supply conduit or reservoir 35 during the oscillatory movement. In this case, outlet openings of the conduit or reservoir 35 can be large without the problem of releasing more liquid than can be supplied by a pump, and the danger of blockage of the openings by particles suspended in the liquid is considerably reduced.

Figure 17 shows another manner of supplying the liquid, for resonators of strip-like nature. In this arrangement, the lower edge of the bending resonator 24 dips into a liquid reservoir 36, at velocity nodes. For this purpose, the lower edge of the resonator 24 of this embodiment is provided with scallop-like projections or extension portions 37 at a spacing of $\lambda/2$. The liquid is then transferred on to the atomisation surface by an acoustic pumping action. Instead of scallop-like projections, it is possible to use projections of any other suitable form.

CLAIMS

1. Apparatus for atomising liquids, the apparatus comprising an ultrasonic excitation system having a horizontal axis, a bending resonator coupled to the ultrasonic excitation system to be oscillated at an ultrasonic frequency having a wavelength λ, and

means for delivering a liquid to a velocity nodal region of the bending resonator, wherein the bending resonator has at least one surface which is inclined with respect to the longitudinal axis of the excitation system and the length of the ultrasonic excitation system is at least approximately equal to $(2n+1)\lambda/4$, where n is 0 or an integer.

2. Apparatus according to claim 1, wherein the bending resonator is in the form of a hollow cone.

3. Apparatus according to claim 2, wherein the length of the ultrasonic excitation system is $\lambda/4$ and the bending resonator is formed by an aperture in a cylindrical portion of the excitation system.

4. Apparatus according to claim 3, wherein the width of the aperture is $(2n+1)\lambda_{air}/4$, wherein n is 0 or an integer.

5. Apparatus according to claim 1, wherein the bending resonator is in the form of a hollow pyramid.

6. Apparatus according to claim 1, wherein the bending resonator has two surfaces which are disposed at an angle relative to each other and the liquid can be supplied along an edge at which said surfaces intersect.

7. Apparatus according to any one of the preceding claims, wherein a heating means for the resonator (e.g. an induction coil) is provided for atomisation of melts, and a cooling means is provided between two adjacent velocity nodal regions of a cylindrical slender portion of the axial excitation system.

8. Apparatus according to any one of claims 1 to 7, wherein the liquid to be atomised can be delivered axially in a jet on to a tip of the resonator.

9. Apparatus according to any one of claims 1 to 7, wherein, for the delivery of the liquid, the excitation system has an axial bore through which a tube which is tuned to resonance is passed and secured to the resonator in the velocity nodal region, a tip of the bending resonator being rounded off in the region of an opening communicating with the tube.

10. Apparatus according to any one of claims 1 to 8, wherein a tip of the bending resonator is provided with a bore and can be fixed by means of a mounting member, and the liquid delivery means is disposed coaxially around the mounting member.

11. Apparatus according to claim 10, wherein, for the delivery of the liquid, the excitation system has an axial bore which is provided with liquid outlet openings in a transitional zone between the excitation system and the resonator.

12. Apparatus according to any one of claims 1 to 7, wherein a cylindrical slender portion of the excitation system is fitted to a tip of the resonator from the outside.

13. Apparatus according to claim 12, wherein, for the delivery of the liquid, an annular pipe is provided in a transitional zone between the resonator and the excitation system, the annular pipe having a plurality of liquid outlet openings.

14. Apparatus for atomising liquids, the apparatus comprising an ultrasonic excitation system having a longitudinal axis, a bending resonator coupled to the ultrasonic excitation system to be oscillated at ultrasonic frequency, and means for delivering a liquid to velocity nodal regions of the bending resonator, the bending resonator being in the form of an elongate narrow strip having a plurality of parallel velocity nodal lines.

15. Apparatus according to claim 14, wherein any desired inclination of a normal to the surface of the bending resonator and thus the atomisation direction can be set by varying the axial direction of the excitation system.

16. Apparatus according to claim 14, wherein a normal to the surface of the resonator and thus the atomisation direction are perpendicular to the axis of the excitation system, and a slender cylindrical portion of the excitation system is at least partly in the form of a spiral so that axial oscillation of the excitation system is converted into a torsional component.

17. Apparatus according to claim 14, claim 15 or claim 16, wherein liquid delivery means are provided for delivering liquid to nodal lines on both sides of the resonator.

18. Apparatus according to claim 14, claim 15 or claim 16, wherein an edge of the bending resonator is provided, at the velocity nodes, with extension portions which dip into a liquid reservoir so that the liquid is transferred on to the resonator surface, for atomisation thereof, by an acoustic pump effect.

19. Apparatus according to any one of claims 1 to 18, wherein a plurality of atomisers are secured to a common liquid supply conduit, for example in a linear or circular arrangement.

20. Apparatus according to any one of claims 1 to 18, wherein a plurality of identical bending resonators having a common excitation system are connected together in a cascade-type formation and the elements of the cascade formation are coupled at velocity antinodes or torsional velocity antinodes.

21. Apparatus according to claim 20, wherein each element of the cascade formation includes spiral members.

22. Apparatus according to claim 20 or claim 21, wherein the resonators in the cascade formation are arranged at different angular positions relative to each other.

23. Apparatus for atomising liquids, the apparatus being substantially in accordance with any of the variants described herein with reference to the accompanying drawings.

Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed, 1981.
Published at the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.